NASA-CR-167487

E82-10208

SR-L1-04032
JSC-16858

AgRISTARS

A Joint Program for Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing

Supporting Research

March 1981

SPRING SMALL GRAINS PLANTING DATE DISTRIBUTION MODEL

T. Hodges and J. A. Artley

(E82-10208) AGRISTARS: SUPPORTING RESEARCH. SPRING SMALL GRAINS PLANTING DATE DISTRIBUTION MODEL (Lockheed Engineering and Management) 33 p HC A03/MF A01 CSCL 02C
N82-23581
Unclas
G3/43 00208

Lockheed Engineering and Management Services Company, Inc.
Houston, Texas 77058

Lyndon B. Johnson Space Center
Houston, Texas 77058

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
SR-L1-04032, JSC-16858		

4. Title and Subtitle	5. Report Date
Spring Small Grains Planting Date Distribution Model	March 1981
	6. Performing Organization Code
7. Author(s) T. Hodges and J. A. Artley	8. Performing Organization Report No. LEMSCO-16018
9. Performing Organization Name and Address Lockheed Engineering and Management Services Company, Inc. 1830 NASA Road 1 Houston, Texas 77058	10. Work Unit No.
	11. Contract or Grant No. NAS 9-15800
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Lyndon B. Johnson Space Center Houston, Texas 77058 Technical Monitor: R. B. MacDonald	13. Type of Report and Period Covered Technical Report
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

A meteorological model to predict the spring grains planting period in the U.S. northern Great Plains was developed in support of the Agriculture and Resources Inventory Surveys through Aerospace Remote Sensing (AgRISTARS) program. Although planting may continue for weeks or months, existing planting date models provide only a median planting date. Planting dates are used in the AgRISTARS program to start meteorology-based phenology models that give estimates of crop growth stages for use with satellite imagery. The range of the planting period is needed to estimate the range of stages to be expected in a satellite acquisition. Planting dates may also be used to run meteorology-based yield models to simulate planting date effects on yield. A model was developed using 996 planting dates at 51 Landsat segments for spring wheat and spring barley in Minnesota, Montana, North Dakota, and South Dakota in 1979. Daily maximum and minimum temperatures and precipitation were obtained from the cooperative weather stations nearest to each segment. The model uses a growing degree day summation modified for daily temperature range to estimate the beginning of planting and uses a soil surface wetness variable to estimate how a fixed number of planting days are distributed after planting begins. For 1979, the model predicts first, median, and last planting dates with root mean square errors of 7.91, 6.61, and 7.09 days, respectively. The model also provides three or four dates to represent periods of planting activity within the planting season. Although the full model has not been tested on an independent data set, it may be suitable in areas other than the U.S. Great Plains where spring small grains are planted as soon as soil and air temperatures become warm enough in the spring for plant growth.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Spring wheat Spring barley Planting Starter model	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	31	

*For sale by the National Technical Information Service, Springfield, Virginia 22161

PRECEDING PAGE BLANK NOT FILMED

SR-L1-04032
JSC-16858

SPRING SMALL GRAINS PLANTING DATE DISTRIBUTION MODEL

Job Order 71-315

This report describes Vegetation/Soils/Field Research activities of the Supporting Research project of the AgRISTARS program.

PREPARED BY

T. Hodges and J. A. Artley

APPROVED BY

J. E. Wainwright, Manager
Development and Evaluation Department

LOCKHEED ENGINEERING AND MANAGEMENT SERVICES COMPANY, INC.

Under Contract NAS 9-15800

For

Earth Resources Research Division
Space and Life Sciences Directorate
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LYNDON B. JOHNSON SPACE CENTER
HOUSTON, TEXAS

March 1981

LEMSCO-16018

PRECEDING PAGE BLANK NOT FILMED

PREFACE

The Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing is a 6-year program of research, development, evaluation, and application of aerospace remote sensing for agricultural resources, which began in fiscal year 1980. This program is a cooperative effort of the National Aeronautics and Space Administration, the U.S. Agency for International Development, and the U.S. Departments of Agriculture, Commerce, and the Interior.

The work which is the subject of this document was performed within the Earth Resources Research Division, Space and Life Sciences Directorate, at the Lyndon B. Johnson Space Center, National Aeronautics and Space Administration. Under Contract NAS 9-15800, personnel of Lockheed Engineering and Management Services Company, Inc., performed the tasks which contributed to the completion of this research.

PRECEDING PAGE BLANK NOT FILMED

CONTENTS

Section		Page
1.	INTRODUCTION	1-1
2.	MATERIALS AND METHODS	2-1
2.1	DATA BASE	2-1
2.2	MODEL DEVELOPMENT	2-1
2.3	GROWING DEGREE DAY ACCUMULATION	2-7
2.4	SPONGE	2-8
2.5	SPONGE-PRECIPITATION VARIABLE	2-10
2.6	CRITICAL VALUES OF GDDR AND SPVAR	2-10
2.7	PLANTING PERIOD DETERMINATION	2-14
3.	RESULTS AND DISCUSSION	3-1
4.	CONCLUSIONS	4-1
5.	REFERENCES	5-1

TABLES

Table		Page
1	1979 SPRING WHEAT AND BARLEY SEGMENTS AND NEAREST WEATHER STATIONS	2-2
2	WEATHER DATA, SPVAR, SPONGE, AND GROWING DEGREE DAY (GDD) ACCUMULATIONS FOR THE WINIFRED, MONTANA, WEATHER STATION NEAR SEGMENT 1948	2-9
3	THE SPONGE-PRECIPITATION VARIABLE AS AN INDICATOR OF SOIL WETNESS AND PLANTING DATES	2-14
4	SEGMENT NUMBERS, NUMBER OF FIELDS, GROUND TRUTH AND PREDICTED FIRST, MEDIAN, AND LAST DATES, FEYERHERM DATE, AND REPRESENTATIVE DATES	3-2
5	RMSE FOR SPRING GRAINS PLANTING DISTRIBUTION MODEL AND FEYERHERM STARTER MODEL VERSUS 1979 GROUND TRUTH	3-3

FIGURES

Figure		Page
1	Segment locations in Minnesota	2-3
2	Segment locations in Montana	2-4
3	Segment locations in North Dakota	2-5
4	Segment locations in South Dakota	2-6
5	Critical value of GDDR	2-12
6	Critical value of SPVAR	2-13
7	1979 planting dates for segment 1518	2-16
8	1979 planting dates for segment 1387	2-17
9	1979 planting dates for segment 1467	2-18
10	1979 planting dates for segment 1987	2-19

1. INTRODUCTION

The Agriculture and Resources Inventory Surveys through Aerospace Remote Sensing (AgRISTARS) is a 6-year program of research, development, evaluation, and application of aerospace remote sensing for agricultural resources beginning in fiscal year (FY) 1980. The AgRISTARS program is a cooperative effort of the National Aeronautics and Space Administration (NASA), the U.S. Agency for International Development (AID), and the U.S. Departments of Agriculture, Commerce, and the Interior (USDA, USDC, and USDI).

The goal of the program is to determine the usefulness, cost, and extent to which aerospace remote sensing data can be integrated into existing or future USDA systems to improve the objectivity, the reliability, the timeliness, and the adequacy of information required to carry out USDA missions. The overall approach is composed of a balanced program of remote sensing research, development, and testing which addresses domestic resource management as well as commodity production information needs.

The technical program is structured into eight major projects as follows:

1. Early Warning/Crop Condition Assessment (EW/CCA)
2. Foreign Commodity Production Forecasting (FCPF)
3. Yield Model Development (YMD)
4. Supporting Research (SR)
5. Soil Moisture (SM)
6. Domestic Crops and Land Cover (DC/LC)
7. Renewable Resources Inventory (RRI)
8. Conservation and Pollution (C/P)

The majority of these projects will make direct use of information on crop phenology. Phenological information is pertinent to classification, acreage and yield estimation, and detection of episodal events.

Where daily meteorological data are available, weather-driven crop phenology models may provide growth stage information (ref. 1). These models require a planting date, daily maximum and minimum temperatures, and daily rainfall. Since planting may last from several weeks to several months in an area, running a phenology model from a single planting date does not give a full picture of growth stage distribution in that area.

The best available spring wheat planting model, the Feyerherm starter model (ref. 2), uses only daily temperature and provides a median planting date with an error of about 1 week. Feyerherm developed his model at the Crop Reporting District (CRD) level. He concluded that rainfall was not statistically significant in his data set, probably because rainstorms rarely affect an entire CRD.

A phenology model that is calculated from the Feyerherm planting date to a Landsat acquisition date gives the growth stage expected within about three weeks of that acquisition. This range of uncertainty is caused by the duration of the planting period and by errors induced by applying a CRD-level model to the segment level.

For crop identification in Landsat imagery, a growth stage distribution or range would be more helpful than a single stage value, at least when the planting period lasts more than about 2 weeks.

For this study, a model was developed to estimate the first, median, and last dates of the spring grains planting period as well as several dates to represent the planting period from daily temperature and rainfall data. A model of soil surface wetness defines periods of potential planting activity and inactivity.

2. MATERIALS AND METHODS

2.1 DATA BASE

In 1979, planting dates were collected for 996 spring wheat and spring barley fields in Minnesota, Montana, North Dakota, and South Dakota at 51 Landsat segments. Planting dates for these two crops did not differ over the region when they were analyzed in an earlier study (ref. 3), so all the dates are treated as one data set.

During the Large Area Crop Inventory Experiment (LACIE), 193 spring wheat and 339 winter wheat planting dates were obtained for fields in Landsat segments for 1974 through 1977 (ref. 4).

A meteorological data base was assembled, and it included daily maximum and minimum temperatures and rainfall collected at a cooperative weather station that was near each segment for the years when planting dates were collected (refs. 4-8). The 1979 segment locations are mapped in figures 1 through 4, and segment weather station coordinates are listed in table 1.

2.2 MODEL DEVELOPMENT

The spring grains planting period is determined by several factors, four of which were considered in this model. These factors are: (1) the soil temperature must be high enough to allow seed germination and plant emergence before the seed is rotted by soil fungus; (2) the probability of a late frost, which could damage the young plants, must be reduced to an acceptable level by delaying planting if the soil warms early in the year; (3) excessive soil surface wetness can prevent mechanized planting operations; and (4) if planting is too late, heat or water stress after the beginning of flowering can reduce yield. Yields of late-planted fields can also be reduced if a frost in the fall occurs before completion of grain-filling.

Factors 1 and 2 were approximated with a growing degree day (GDD) function fit to the 1979 planting dates to determine the initial date of the planting period.

Table 1.- 1979 SPRING WHEAT AND BARLEY SEGMENTS AND NEAREST WEATHER STATIONS

Segment number	Segment coordinates		County	State	Weather station	Station number	Station coordinates		Elevation, feet
	N	W					N	W	
1380	44° 35'	95° 13'	Redwood	MN	Lamberton SW Exp.	4546	44° 15'	95° 19'	1144
1387	48° 27'	98° 38'	Ramsey	ND	Edmore 1 N	2525	48° 25'	98° 28'	1520
1392	47° 57'	99° 14'	Benson	ND	Sheyenne	8057	47° 50'	99° 07'	1480
1394	48° 52'	102° 23'	Burke	ND	Bowbells	0961	48° 48'	102° 15'	1958
1399	46° 14'	96° 58'	Richland	ND	Hankinson RR Sta.	3908	46° 04'	96° 54'	1068
1457	48° 16'	101° 46'	Ward	ND	Foxholm 7 N	3217	48° 27'	101° 35'	1609
1461	48° 13'	99° 59'	Pierce	ND	Leeds	5078	48° 17'	99° 26'	1530
1467	48° 42'	99° 23'	Towner	ND	Rolla 3 NW	7664	48° 54'	99° 40'	1950
1472	46° 42'	98° 07'	Barnes	ND	Valley City 3 NNW	8937	46° 58'	98° 02'	1210
1473	47° 10'	96° 54'	Cass	ND	Fargo WSO AP	2859	46° 54'	96° 48'	896
1485	45° 28'	100° 52'	Dewey	SD	Mobridge	5691	45° 32'	100° 26'	1668
1514	48° 20'	96° 07'	Marshall	MN	Agassiz Refuge	0050	48° 18'	95° 59'	1142
1518	48° 35'	96° 15'	Roseau	MN	Agassiz Refuge	0050	48° 18'	95° 59'	1142
1524*	45° 22'	94° 56'	Kandiyohi	MN	New London	5842	45° 18'	94° 56'	1240
1566	45° 52'	95° 50'	Grant	MN	Elbow Lake	2476	45° 59'	95° 58'	1195
1571	47° 06'	102° 46'	Dunn	ND	Dickinson Exp Sta.	2188	46° 53'	102° 48'	2640
1584	48° 49'	97° 15'	Pembina	ND	Hallock MN	3455	48° 46'	96° 57'	820
1599	45° 27'	98° 51'	Edmonds	SD	Aberdeen WSO AP	0020	45° 27'	98° 26'	1296
1602	48° 21'	102° 25'	Mountrail	ND	Powers Lake 1 N	7281	48° 34'	102° 38'	2205
1611	48° 51'	101° 23'	Bottineau	ND	Mohall	6025	48° 48'	101° 31'	1640
1612	48° 03'	100° 17'	McHenry	ND	Drake 9 NE	2304	48° 02'	100° 17'	1550
1617	48° 55'	98° 49'	Cavalier	ND	Munich 11 SSW	6195	48° 31'	98° 55'	1530
1619	48° 04'	97° 30'	Grand Forks	ND	Grand Forks FAA AP	3616	47° 57'	97° 11'	839
1627	47° 55'	103° 32'	McKenzie	ND	Watford City 14 S	9246	47° 36'	103° 17'	1965
1630	47° 02'	102° 06'	Mercer	ND	Hebron	4102	46° 54'	102° 03'	2158
1636	46° 48'	98° 32'	Stutsman	ND	Jamestown St. Hos.	4418	46° 53'	98° 41'	1457
1645	47° 33'	96° 56'	Traill	ND	Hillsboro	4203	47° 24'	97° 04'	900
1650	46° 32'	102° 10'	Hettinger	ND	Mott	6155	46° 23'	102° 20'	2420
1653	47° 01'	100° 20'	Burleigh	ND	Tuttle	8850	47° 08'	100° 00'	1880
1656	46° 36'	101° 13'	Morton	ND	Carson	1370	46° 25'	101° 34'	2310
1658	46° 05'	98° 19'	Dickey	ND	Ellendale 8 NNW	2605	46° 07'	98° 34'	1480
1661	46° 16'	99° 45'	McIntosh	ND	Wishek	9515	46° 15'	99° 34'	2015
1664	46° 11'	97° 24'	Sargent	ND	Forman 5 SSE	3117	46° 02'	97° 36'	1250
1676	43° 36'	99° 02'	Brule	SD	Academy	0043	43° 28'	99° 05'	1675
1689	44° 46'	99° 57'	Sully	SD	Onida 4 NW	6292	44° 44'	100° 09'	1850
1725	48° 19'	114° 12'	Flathead	MT	Creston	2104	48° 11'	114° 08'	2940
1755	44° 03'	98° 53'	Jerauld	SD	Wessington Springs	9070	44° 05'	98° 34'	1637
1784	43° 48'	97° 05'	Minnehaha	SD	Wentworth 2 WNW	9042	44° 01'	97° 00'	1690
1825	47° 15'	96° 10'	Norman	MN	Mahnomen 1 W	5012	47° 19'	95° 59'	1203
1835	46° 20'	95° 57'	Otter Tail	MN	Fergus Falls	2768	46° 17'	96° 04'	1320
1842	44° 43'	95° 48'	Yellow Medicine	MN	Montevideo 1 SW	5563	44° 56'	95° 45'	985
1843*	45° 40'	94° 09'	Benton	MN	St. Cloud WSO AP	7294	45° 33'	94° 04'	1037
1909	47° 04'	99° 42'	Kidder	ND	Pettibone	7047	47° 07'	99° 31'	1855
1917	46° 39'	100° 27'	Emmons	ND	Fort Yates	3207	46° 06'	100° 38'	1653
1918	46° 18'	101° 18'	Grant	ND	Carson	1370	46° 25'	101° 35'	2310
1920	46° 03'	101° 00'	Sioux	ND	Fort Yates	3207	46° 06'	100° 38'	1653
1924	46° 28'	98° 50'	Lamoure	ND	Gackle	3309	46° 38'	99° 08'	1951
1948	47° 37'	109° 20'	Fergus	MT	Winifred	9033	47° 33'	109° 23'	3243
1960	45° 40'	97° 00'	Roberts	SD	Sisseton 2 E	7742	45° 40'	97° 00'	1190
1974	46° 25'	97° 50'	Ransom	ND	Lisbon	5220	46° 26'	97° 40'	1089
1987	47° 49'	96° 41'	Polk	MN	Crookston NW Exp.	1891	47° 48'	96° 37'	883

*Barley only

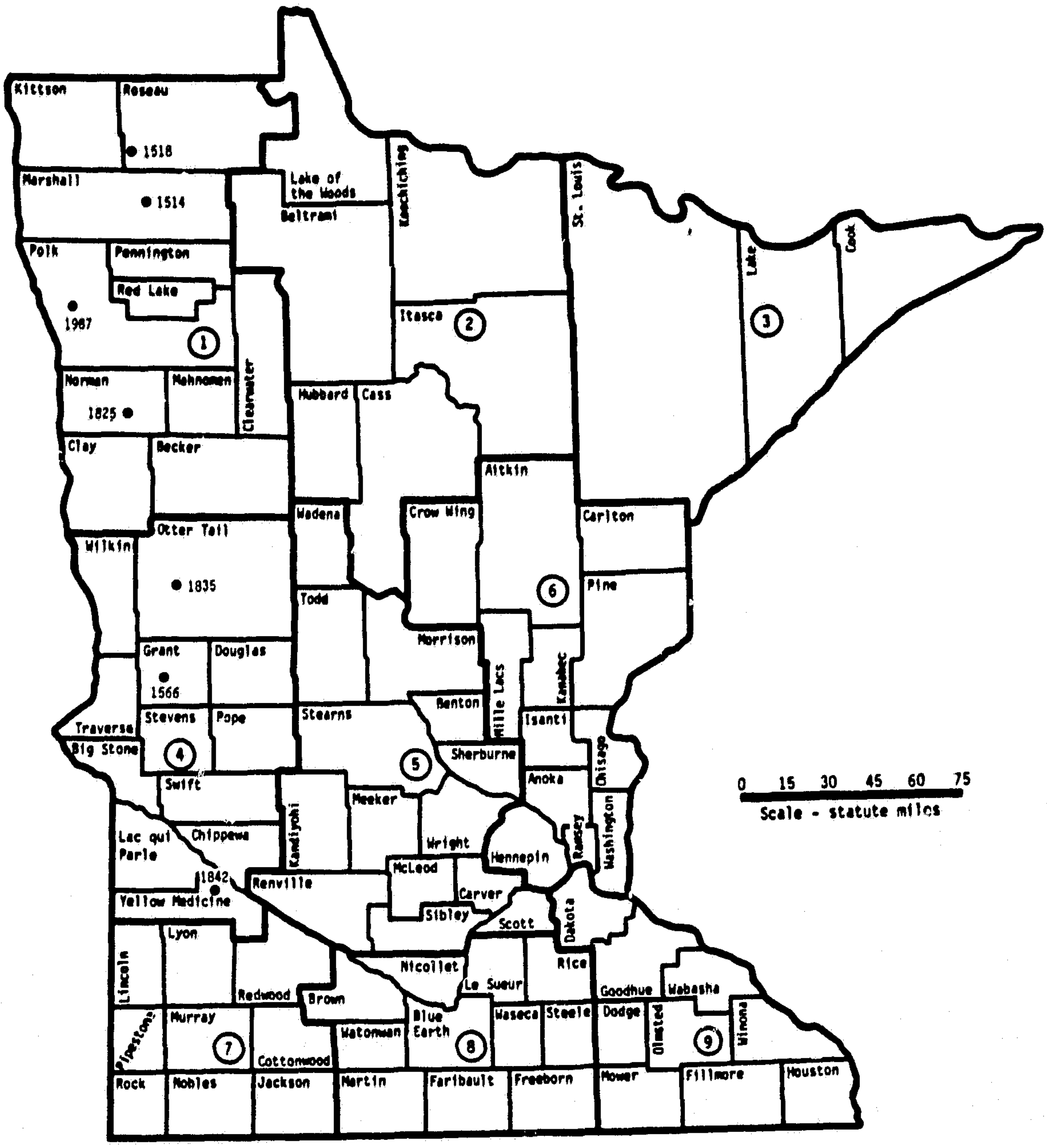

Figure 1.- Segment locations in Minnesota.

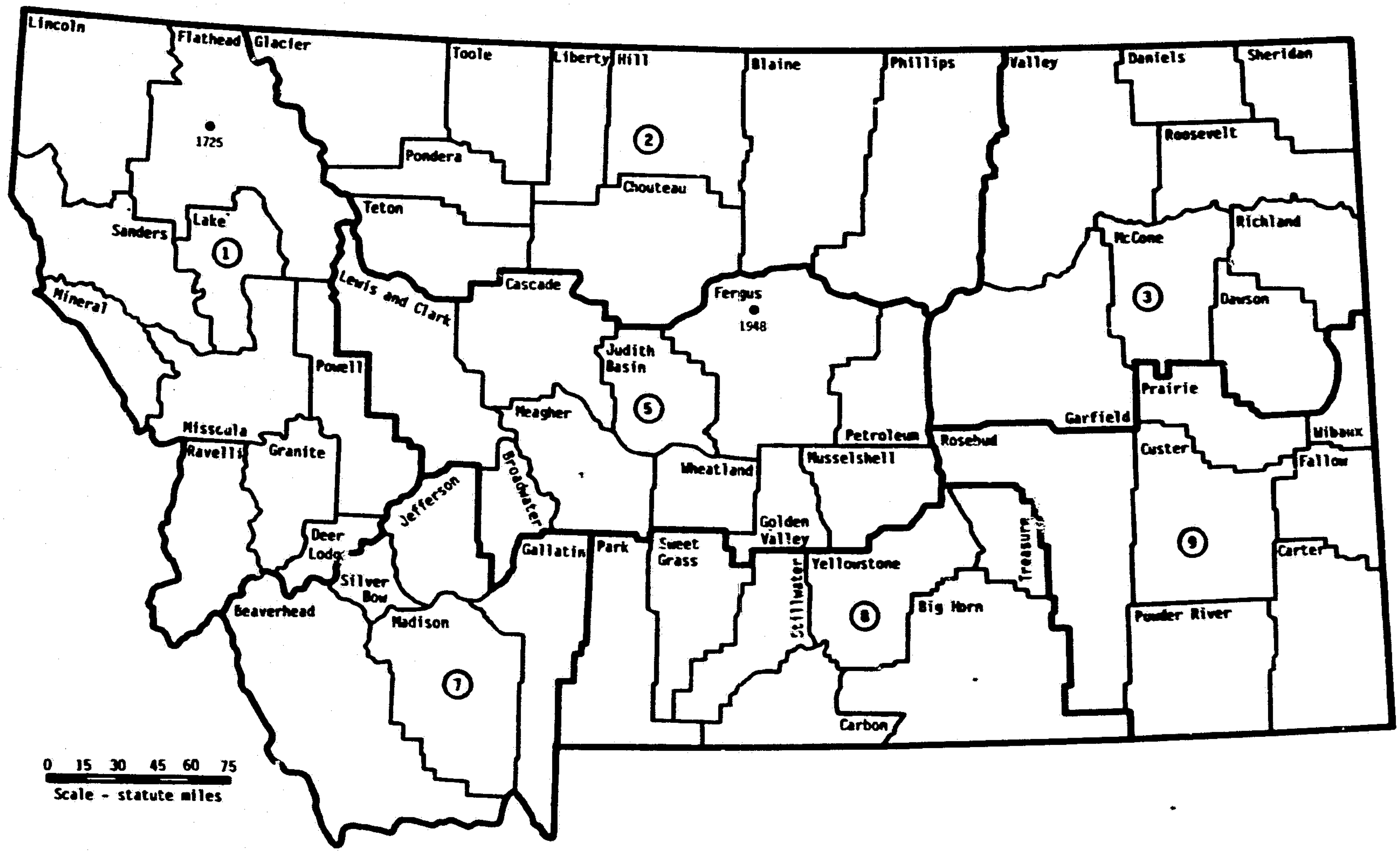

Figure 2.- Segment locations in Montana.

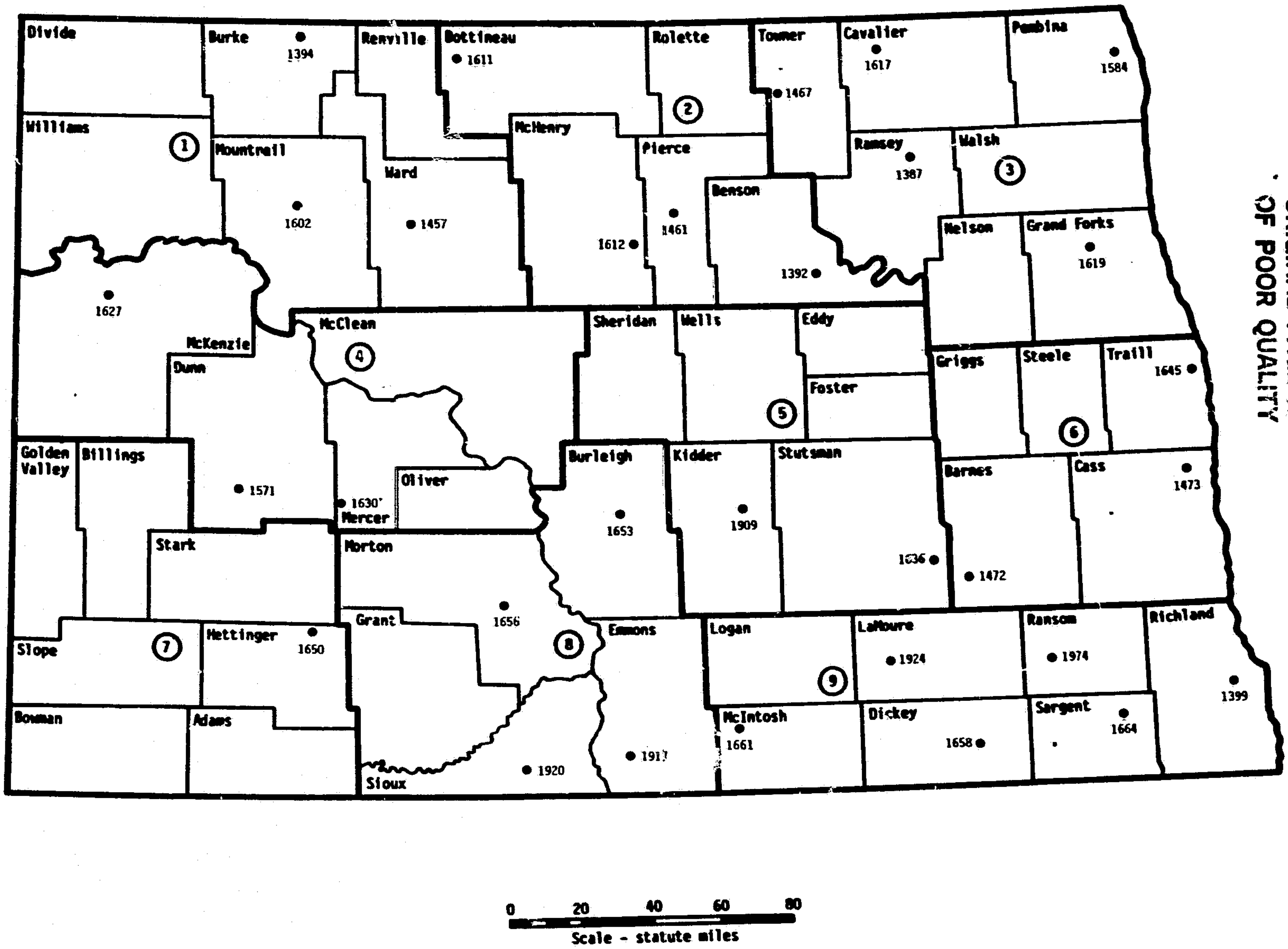

Figure 3.- Segment locations in North Dakota.

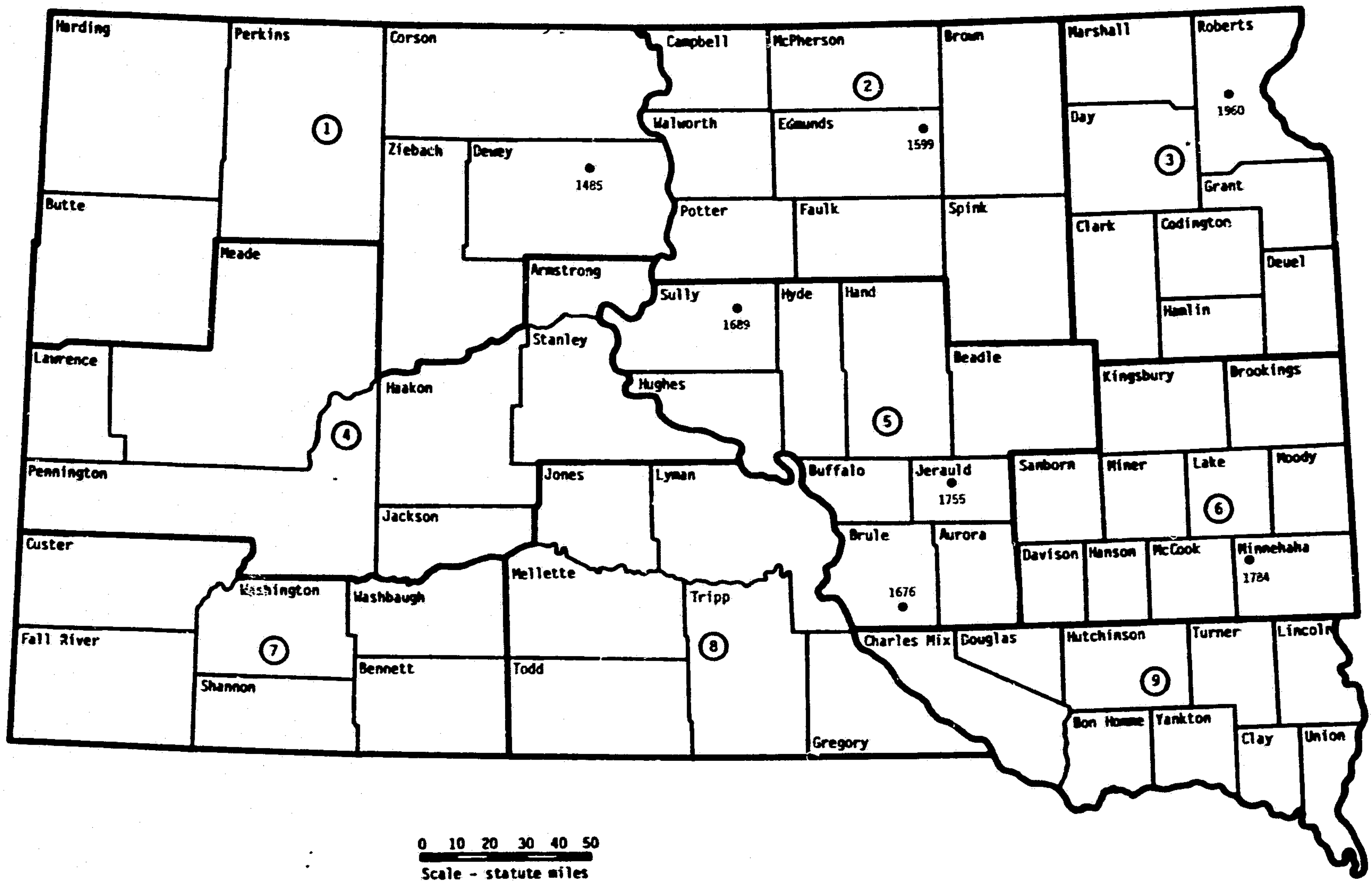

Figure 4.- Segment locations in South Dakota.

Factor 3 was modeled by creating a sponge-precipitation variable (SPVAR) from the surrogate soil moisture variable, sponge (ref. 9), and daily rainfall.

Factor 4 was approximated by setting an arbitrary limit to the number of predicted planting days. If planting must be postponed for one reason or another, some farmers will plant later than usual, even though the probability of yield-reducing events has increased.

Soil texture, slope, and elevation relative to surrounding fields are factors which affect how surface wetness responds to daily weather. These factors affect the rate of infiltration of rainfall, the rate of drainage, the balance of runoff and run-on for the field, water diffusivity, and soil water storage capacity. The process of soil warming is driven by heat from the sun and the air. This process is influenced by soil heat capacity and heat conductivity which depend upon soil water content and soil texture. Further complications for modeling occur if the soil is too dry for seed germination. If this occurs, a farmer may elect either to wait for rainfall or to plant anyway, hoping that the seeds will not be eaten, molded, or otherwise killed before precipitation wets the soil. These processes are not modeled in this study because soil characteristics are not adequately known for Landsat segments in the U.S., and they are essentially unavailable for segments in many foreign areas.

2.3 GROWING DEGREE DAY ACCUMULATION

Cross and Zuber (ref. 10) list many degree day (DD) functions which are variations of the general form of daily temperature deviation in degrees from a base temperature, and Hodges and Doraiswamy (ref. 1) review several DD phenology models. For spring grains planting in the U.S. Great Plains, a base temperature of 32° F (GDD32) with a modification to include daily temperature ranges (GDDR) gave the best results for planting. This is supported by the observation that wheat begins growing at just above freezing. The GDD functions are:

$$GDD32 = \begin{cases} (Tmax + Tmin)/2 - 32; \text{ for } GDD32 > 0 \\ 0; \text{ for } GDD32 \leq 0 \end{cases}$$

$$GDDR = GDD32 - .01 \times (Tmax - Tmin)^2; \text{ for } GDDR > 0 .$$

where Tmax and Tmin are daily maximum and minimum temperatures in degrees Fahrenheit. When the daily temperature range is less than 20° F, the range adjustment has little affect on GDD accumulation. The adjustment for daily range is most needed for dry continental regions such as Montana or the U.S.S.R. spring wheat regions where high daytime temperatures and substantial GDD32 accumulation occur while nighttime temperatures frequently remain well below freezing. Table 2 lists maximum and minimum temperatures and GDD32 and GDDR accumulations for the planting season for Winifred, Montana, near segment 1948.

2.4 SPONGE

Sponge is a simple moisture variable based on Class A pan evaporation which may be used to simulate the relative moisture of the soil profile on a scale of 0 (dry) to 8 (saturated). In the absence of observations, daily class A pan evaporation (EP) is estimated from daily maximum and minimum temperatures:

$$EP = [0.3473 \times vapor\ (Tmax) - 0.2644 \times vapor\ (Tmin) + 0.2163]/30$$

where vapor is the saturation vapor pressure over water,

$$vapor = 6.11 * \exp. \left(\frac{-176204.2621 + 5597.607915*T - 2.850772636*T^2}{125416.2 + 273*T} \right)$$

In the above equation, temperature T is in degrees Fahrenheit, vapor pressure is in millibars and evaporation is in inches.

The contents of sponge is estimated as a function of the previous day's contents and the present day's pan evaporation and rainfall.

TABLE 2.- WEATHER DATA, SPVAR, SPONGE, AND GROWING DEGREE DAY (GDD) ACCUMULATIONS FOR THE WINIFRED, MONTANA, WEATHER STATION NEAR SEGMENT 1948

Julian Date	Max. °F	Min. °F	Precip., inches	SPVAR	Sponge	GDD32	GDDR
98	64.0	25.0	0.0	0.33	3.96	167.5	45.40
99	63.0	33.0	0.0	0.26	3.87	183.5	52.40
100	59.0	32.0	0.17	0.68	3.97	197.0	58.61
101	39.0	30.0	0.0	0.34	3.95	199.5	60.30
102	40.0	28.0	0.0	0.23	3.92	201.5	60.86
103	50.0	21.0	0.0	0.17	3.86	205.0	60.86
104	54.0	26.0	0.0	0.14	3.80	213.0	61.02
105	58.0	31.0	0.0	0.11	3.73	225.5	66.23
106	72.0	32.0	0.0	0.10	3.61	245.5	70.23
107	76.0	41.0	0.0	0.08	3.49	272.0	84.48
108	68.0	37.0	0.48	1.86	3.87	292.5	95.37
109	49.0	31.0	0.01	0.93	3.84	300.5	100.13
110	51.0	28.0	0.01	0.62	3.80	308.0	102.34
111	54.0	26.0	0.0	0.46	3.74	315.0	102.50
112	53.0	28.0	0.02	0.37	3.70	324.5	104.75
113	40.0	31.0	0.31	1.24	3.99	328.0	107.44
114	39.0	30.0	0.28	2.03	4.14	330.5	109.13
115	56.0	29.0	0.0	1.01	4.07	341.0	112.34
116	56.0	40.0	0.0	0.68	4.02	357.0	125.78
117	65.0	25.0	0.0	0.51	3.91	370.0	125.78
118	63.0	38.0	0.0	0.41	3.83	388.5	138.03
119	59.0	28.0	0.0	0.34	3.76	400.0	139.92
120	63.0	27.0	0.0	0.29	3.67	413.0	139.96
121	53.0	33.0	0.21	0.80	3.83	424.0	146.96
122	57.0	30.0	0.0	0.40	3.76	435.5	151.17
123	56.0	31.0	0.0	0.27	3.70	447.0	156.42
124	56.0	33.0	0.0	0.20	3.64	459.5	163.63
125	58.0	44.0	0.0	0.16	3.59	478.5	180.67
126	50.0	31.0	0.41	1.62	3.96	487.0	185.56
127	45.0	31.0	0.07	1.91	3.99	493.0	189.60
128	45.0	30.0	0.0	0.96	3.95	498.5	192.85
129	46.0	35.0	0.0	0.64	3.92	507.0	200.14
130	58.0	23.0	0.0	0.48	3.84	515.4	200.14
131	58.0	41.0	0.16	0.63	3.94	533.0	214.75
132	61.0	24.0	0.17	1.33	4.02	543.5	214.75
133	60.0	39.0	0.0	0.66	3.95	561.0	227.84
134	65.0	33.0	0.0	0.44	3.86	578.0	234.60
135	80.0	41.0	0.0	0.33	3.70	606.5	247.89
136	80.0	46.0	0.09	0.27	3.65	637.5	267.33
137	69.0	49.0	0.0	0.22	3.55	659.5	280.33
138	66.0	41.0	0.0	0.19	3.47	681.0	295.58
139	62.0	39.0	0.08	0.28	3.49	699.5	308.79
140	67.0	30.0	0.0	0.14	3.39	716.0	311.60
141	72.0	40.0	0.0	0.09	3.29	740.0	325.36
142	70.0	41.0	0.0	0.07	3.20	763.5	340.45
143	75.0	35.0	0.0	0.06	3.09	786.5	347.45
144	78.0	41.0	0.0	0.05	2.97	814.0	361.26
145	76.0	48.0	0.02	0.04	2.90	844.0	383.42
146	84.0	43.0	0.0	0.03	2.76	875.5	398.11
147	82.0	53.0	0.10	0.03	2.76	911.0	425.20
148	57.0	42.0	0.10	0.28	2.82	928.5	440.45
149	56.0	40.0	0.0	0.14	2.78	944.5	453.89
150	65.0	35.0	0.0	0.09	2.72	962.5	462.89
151	61.0	36.0	0.05	0.07	2.71	979.0	473.14
152	72.0	32.0	0.09	0.24	2.72	999.0	477.14
153	77.0	41.0	0.0	0.12	2.62	1026.0	491.18
154	83.0	50.0	0.0	0.08	2.51	1060.5	514.79
155	81.0	41.0	0.0	0.06	2.40	1089.5	527.79
156	82.0	53.0	0.0	0.05	2.31	1125.0	554.88
157	74.0	45.0	0.0	0.04	2.24	1152.5	573.97
158	56.0	38.0	0.0	0.03	2.21	1167.5	585.73
159	64.0	31.0	0.0	0.03	2.15	1183.0	590.34
160	72.0	40.0	0.0	0.03	2.09	1207.0	604.10
161	84.0	43.0	0.0	0.02	1.99	1238.5	618.79
162	90.0	44.0	0.0	0.02	1.88	1273.5	632.63
163	96.0	45.0	0.06	0.02	1.81	1312.0	645.12
164	95.0	48.0	0.0	0.02	1.69	1351.5	662.53
165	86.0	47.0	0.03	0.02	1.63	1386.0	681.82
166	72.0	41.0	0.0	0.02	1.59	1410.5	696.71
167	67.0	40.0	0.30	0.55	1.85	1432.0	710.92
168	75.0	47.0	0.02	0.28	1.81	1461.0	732.08
169	74.0	47.0	0.0	0.18	1.76	1489.5	753.29

$$\text{sponge}_i = \begin{cases} \text{sponge}_{i-1} + \text{PRE}_i - \text{EP}_i \times (\text{sponge}_{i-1}/\text{Cap}), & \text{sponge}_i < 8 \\ 8, & \text{sponge}_i \geq 8 \end{cases}$$

In the above equation, sponge_i is today's sponge contents, sponge_{i-1} is the sponge contents yesterday, PRE_i is the daily precipitation, and cap is the sponge's total water holding capacity (8"). Sponge contents are initialized at half capacity on the last day of the previous year.

Rainfall greater than that needed to bring the sponge to capacity is considered runoff or drainage from the simulated soil profile (ref. 9).

2.5 SPONGE-PRECIPITATION VARIABLE

The sponge precipitation variable (SPVAR) is used to estimate soil surface wetness from rainfall, sponge, and days since the last period of precipitation which increased the sponge.

$$\text{SPVAR} = \left(\sum_{j=n}^{n+k-1} \text{PRE}_i\right) \times (\text{sponge}_{n+k-1})/[(i+1) - (n+k-1)]$$

where

i = the current date

n = the first date of the most recent period in which the sponge increased

k = the length of that period

If the last rainfall occurred on a single day rather than several consecutive days, then k is one.

2.6 CRITICAL VALUES OF GDDR AND SPVAR

To estimate the start of planting from GDDR, we determined the critical value which gave the best separation of planting days from nonplanting days. We calculated GDDR summation values for all days in the observed planting period (Julian days 98 to 178) for all the segments.

Figure 5 shows the percentage of the values in each 10 GDDR increment for reported planting and nonplanting days. Planting activity increases sharply at about 160 GDDR. The GDDR value that minimizes both errors of commission (predict no planting when planting is reported) and errors of omission (predict planting can occur when no planting is reported) is the value between 180 and 190 where the two curves cross. For predicting planting dates, errors of omission have little significance since farmers planting a limited number of fields cannot be expected to plant on every possible day. Therefore, a critical value of 180 GDDR was chosen as the beginning of the planting period. At this GDDR, only 7.7% of the fields have been planted.

A similar analysis was conducted on SPVAR. Percentages of planting and nonplanting days in each 0.2 increment of SPVAR are plotted in fig. 6. The curve for planting days crosses below the curve for nonplanting days at a SPVAR value of 0.6 and continues roughly parallel but slightly below until a SPVAR of 2.0. The planting days' curve decreases sharply after this value, while the nonplanting days' curve continues to decrease gradually. Setting the critical value for SPVAR at 2.0 minimizes errors of commission.

The SPVAR value of 2.0 as an indicator of planting days was also tested by comparing the distribution of SPVAR for all days in the spring and fall planting periods for the LACIE and 1979 segments versus its distribution over the reported plantings for these periods. The results of this test are shown in table 3. Of the actual planting days, 95.6% in 1979 and 98.2% in 1974-1977 had SPVAR less than or equal to 2.0 compared to 83.5% and 91.9% of all days. This shows that farmers generally avoided planting on days with SPVAR greater than 2.0. The exceptions may be days when rainfall occurred at the weather station but not at the segment (up to 20 miles away), or they may be because of extremes of soil texture or errors in planting date observation.

We should not expect as sharp a separation of planting and nonplanting days with the SPVAR as with the GDDR variable for several reasons. Rainfall is much more variable over short distances, such as 10 to 20 miles, than is temperature, so the weather station temperatures will usually represent the

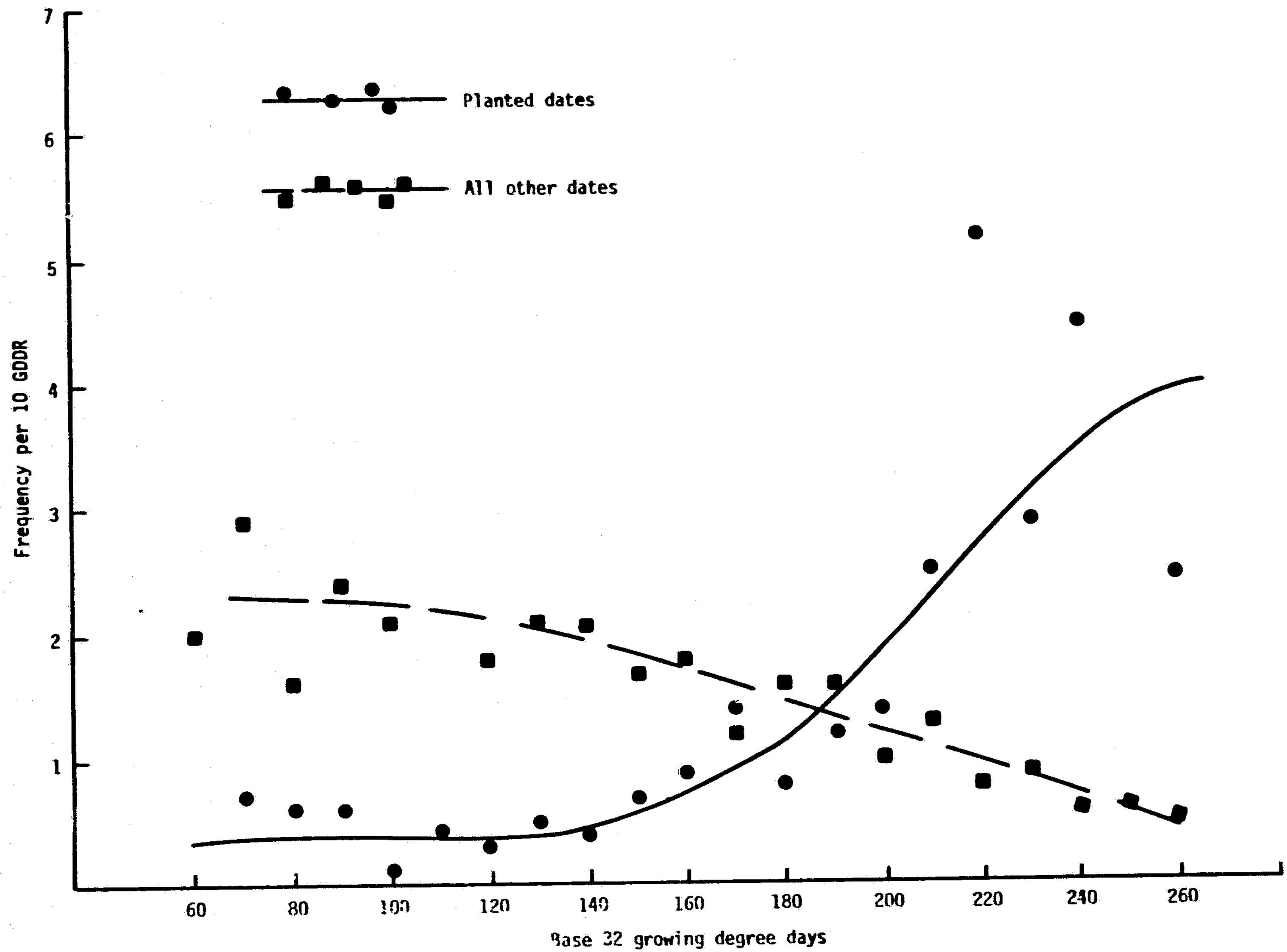

Figure 5.- Critical value of GDDR.

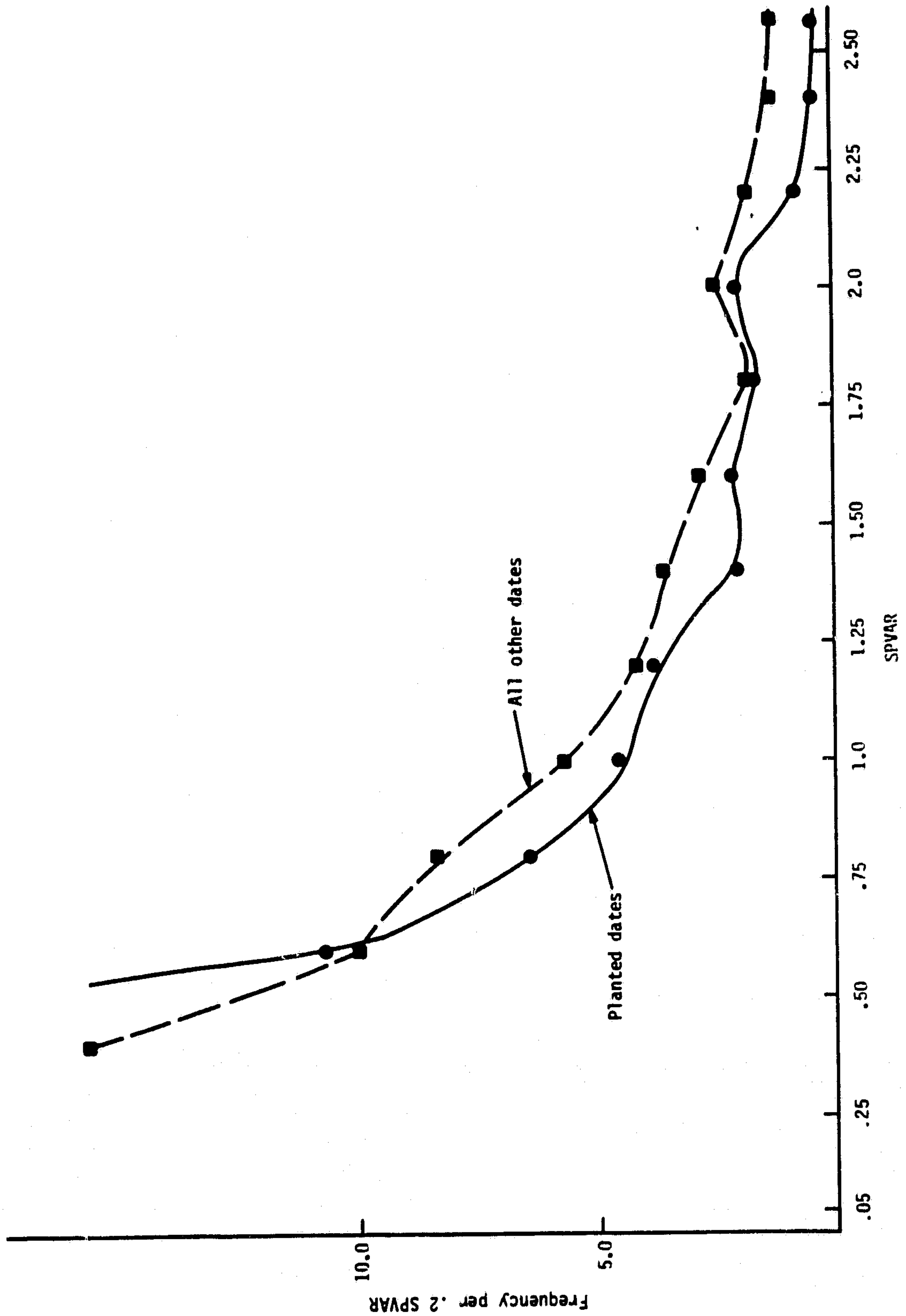

Figure 6.- Critical value of SPVAR.

TABLE 3.- THE SPONGE-PRECIPITATION VARIABLE AS AN INDICATOR OF SOIL WETNESS AND PLANTING DATES

All dates:	N	%<2.0	Max.	<99%	<95%	<90%
1979 Spring grains	4131	83.5	40.96	13.20	5.15	3.09
1975-77 Spring wheat	6900	88.7*	28.16*	8.77*	3.94*	2.23*
1974-78 Winter wheat	6900	95.1*	53.2*	5.46*	1.95*	1.01*
All 1974-77	13800	91.9	53.2	7.58	3.00	1.63
Planting dates:						
1979 Spring grains	996	95.6	17.14	4.75	1.91	1.43
1975-77 Spring wheat	193	98.3	4.52	4.52	1.41	1.10
1974-78 Winter wheat	339	98.3	3.68	3.26	1.08	0.45
All 1974-77	532	98.2	4.52	3.33	1.34	0.85

*1974-77, The Large Area Crop Inventory Experiment.

nearby segments better than the weather station precipitation. As discussed above, several factors affect surface soil wetness, whereas only aspect (north- or south-facing terrain) and elevation will cause large variation in local temperatures.

2.7 PLANTING PERIOD DETERMINATION

Planting begins the first day on which SPVAR is less than or equal to 2.0 when GDDR exceeds 180.

For each segment, the number of days on which SPVAR was less than or equal to 2.0 from the estimated first planting date to the reported final planting date was calculated. The mean length of this period was found to be 22 days. Thus, the first 22 days with SPVAR less than or equal to 2.0 when GDDR reaches 180 are the modeled planting days. The tenth modeled planting day estimates the median planting date.

In order to select several dates to represent the whole planting period, one may consider it to be made of several subperiods, each consisting of at least one modeled planting day. The 22 days are assigned to subperiods as follows:

1. All consecutive modeled planting days are part of one subperiod.

2. When two subperiods are separated by a single day of SPVAR greater than 2, both subperiods and the intervening day are combined into a single subperiod.

3. A single planting day separated from all other subperiods is assigned to the nearest subperiod. If two subperiods are equidistant, the single day is assigned to the subperiod nearer to the median date. If the single day is the median date, it is assigned to the earlier subperiod.

Demiperiods are created from subperiods as needed:

1. Subperiods of 11 to 15 days are divided in two. An extra day is assigned to the demiperiod nearer to the median. If the extra day is the median, it is assigned to the preceding demiperiod.

2. Subperiods longer than 15 days are divided into 3 demiperiods. One extra day is assigned to the central demiperiod, and, if needed, the second extra day is assigned to the last demiperiod.

The median date of each demiperiod is selected as the representative date. For subperiods or demiperiods of even length, the date nearer the overall median is selected as the representative date.

Fig. 7 shows planting days, representative dates, and SPVAR for segment 1518. Figures 8 through 10 show reported and predicted planting days and representative dates for segments 1387, 1467, and 1987.

1979 PLANTING DATES

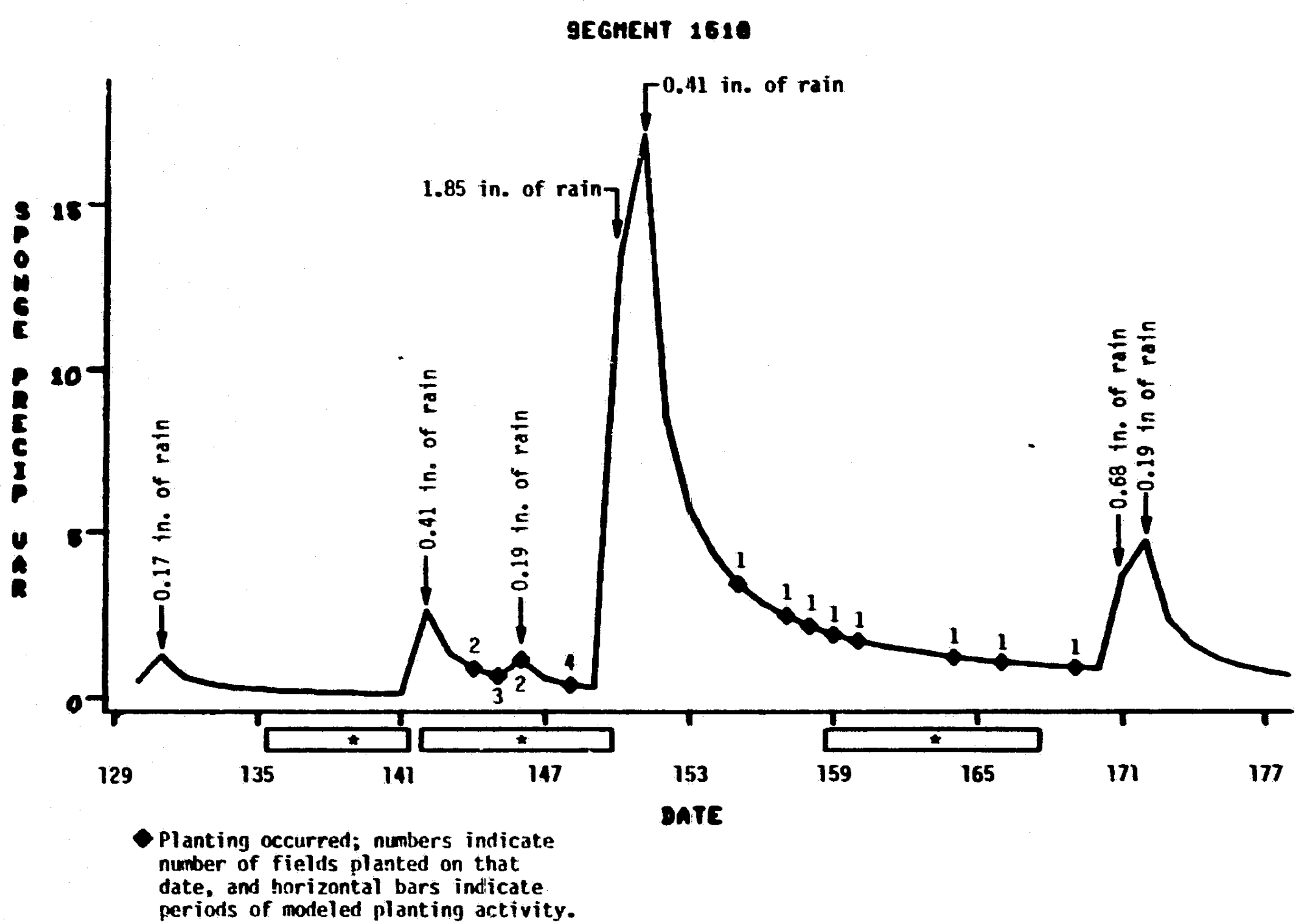

Figure 7.- 1979 planting dates for segment 1518.

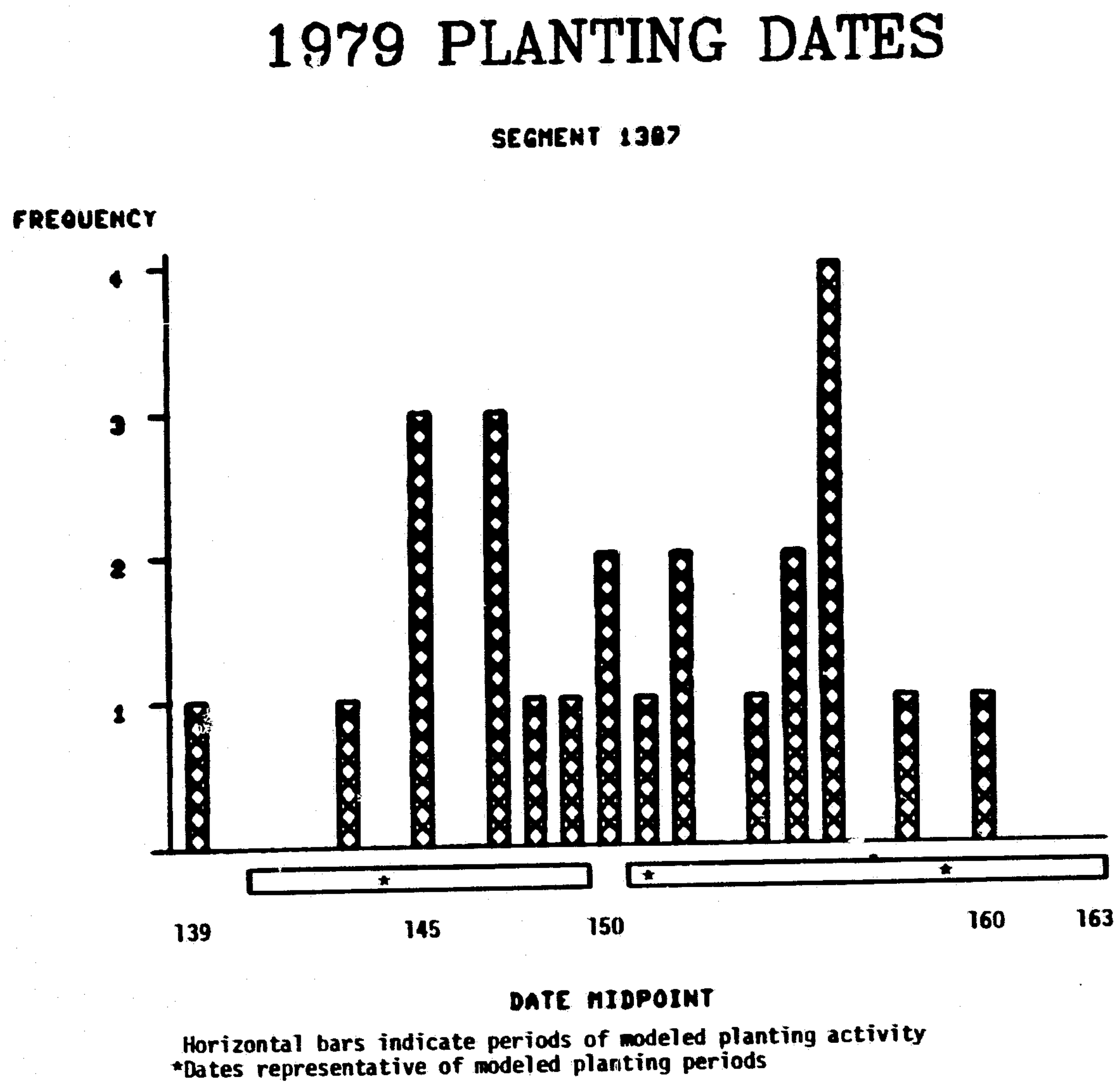

Figure 8.- 1979 planting dates for segment 1387.

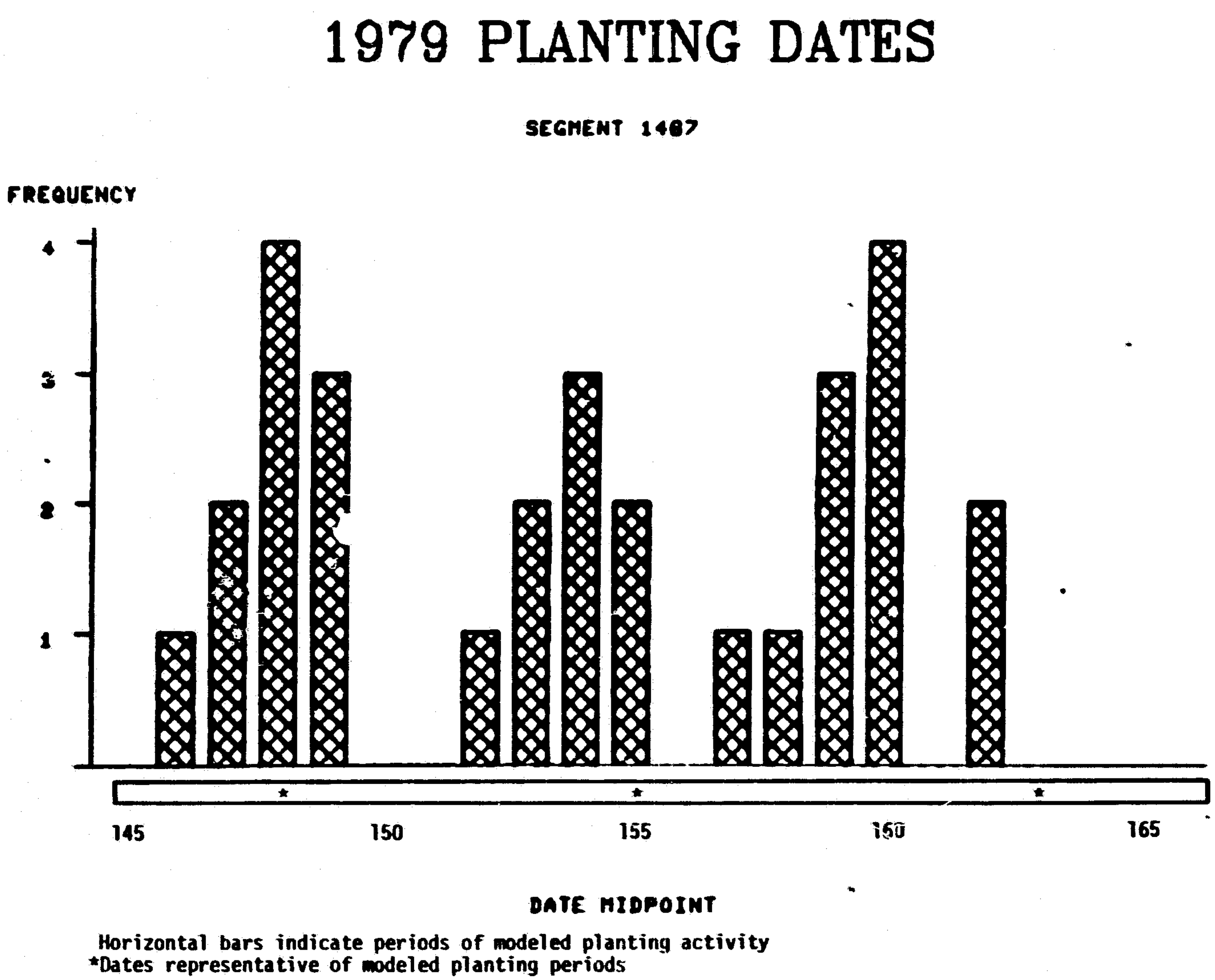

Figure 9.- 1979 planting dates for segment 1467.

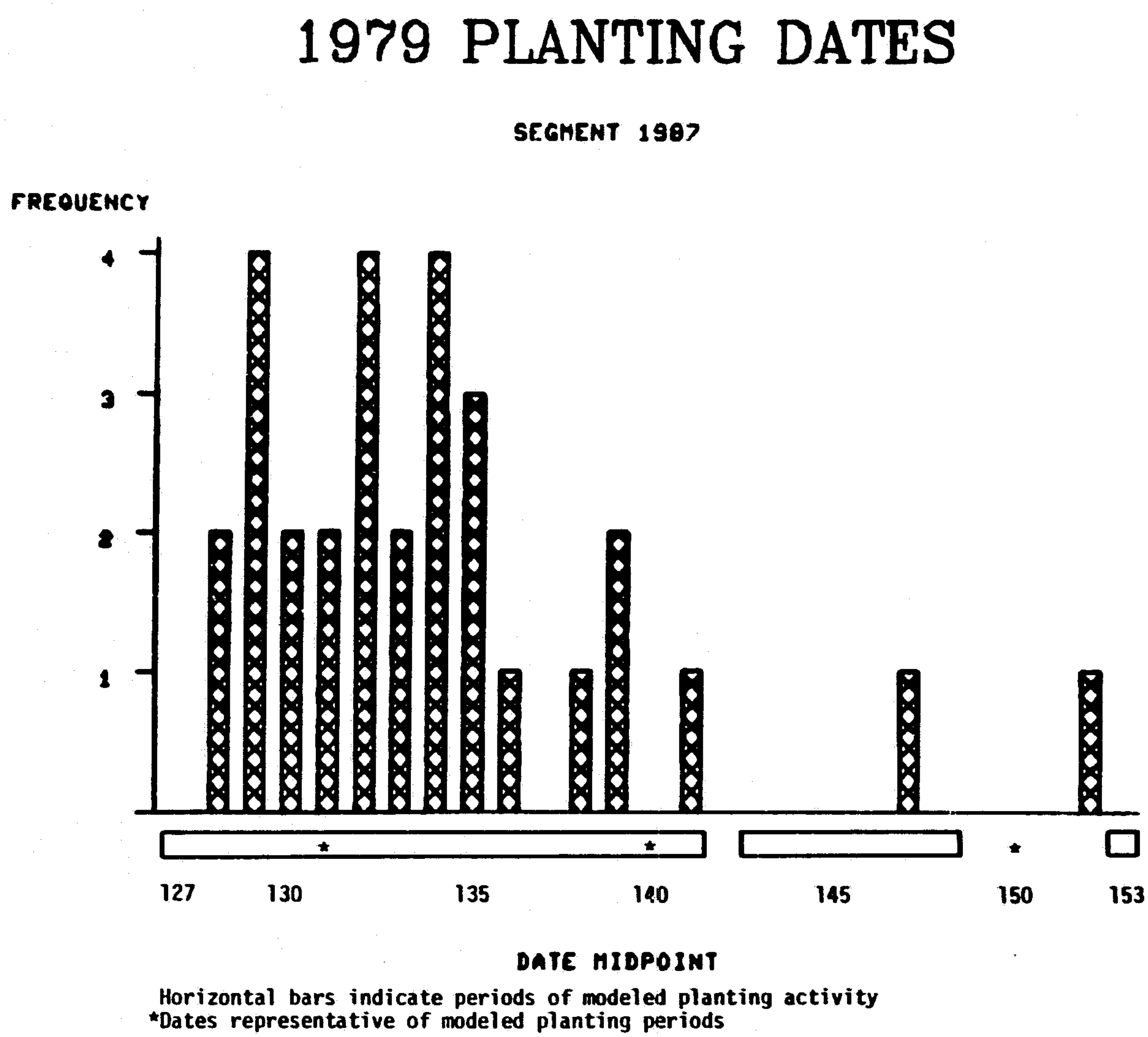

Figure 10.- 1979 planting dates for segment 1987.

3. RESULTS AND DISCUSSION

Table 4 lists reported and predicted first, median, and last planting dates for the segments analyzed in this study. The table also gives the three or four representative dates generated by the model for each segment and the Feyerherm starter model planting dates.

Table 5 summarizes results of model predictions and compares them to the Feyerherm planting dates and to ground truth planting dates. Our model estimates median planting dates for the 1979 segments with an RMSE of 6.61 compared to 8.49 for the Feyerherm model. Since our model has been fitted to the 1979 data, it will not necessarily be more accurate than the Feyerherm model for other years or other locations. RMSE values of 7.91 and 7.09 for first and last planting dates respectively indicate good estimation of the beginning and end of planting. If five early fields are dropped from three segments, then the RMSE for the first day of planting is only 6.78.

For several segments, predicted and reported planting periods were quite different. Planting at segment 1918 (Grant County, North Dakota) was reported about 30 days earlier than predicted. The reported planting dates were inconsistent with weather data from the Carson weather station. Only 5 days with mean temperatures above freezing had occurred by the first day of planting. All minimum temperatures had been and continued to be below freezing for 4 more days after the first reported planting day. In addition, segments in adjoining counties were planted 20 to 35 days later. Although it is possible that the fields in the segment had a more southerly aspect than either the Carson weather station or the neighboring segments, we did not include this segment in our analysis because of these inconsistencies. Three other segments (1380, 1524, and 1843) were not analyzed because each had less than five fields with reported planting dates. Removing these four segments left 969 fields for analysis.

Several segments were planted about 2 weeks earlier (1661, 1689, and 1755) or later (1473 and 1599) than predicted by the model (table 4). These discrepancies may be attributed to climatic differences between segments and weather stations or to error in the model.

TABLE 4.- SEGMENT NUMBERS, NUMBER OF FIELDS, GROUND TRUTH, PREDICTED FIRST, MEDIAN, AND LAST DATES, FEYERHERM DATES, AND REPRESENTATIVE DATES

Segment	No. fields	Ground truth			Predicted			Feyerherm dates	Representative dates			
		First	Median	Last	First	Median	Last					
1387	24	139	151	160	141	151	163	153	144	151	159	
1392	19	144	153	163	137	146	158	148	140	147	155	
1394	16	145	155	166	143	152	164	156	146	153	161	
1399	30	120	136	145	126	136	148	144	129	136	144	
1457	22	152	160	163	146	156	168	159	149	156	164	
1461	27	141	148	161	141	150	162	155	144	151	159	
1467	29	146	154	162	145	154	166	159	148	155	163	
1472	27	138	145	159	137	146	159	148	140	147	155	
1473	30	135	140	161	122	135	147	142	123	132	138	145
1485	24	108	124	146	115	124	136	134	118	125	133	
1514	29	139	158	168	136	146	167	148	139	146	163	
1518	19	144	148	169	136	146	167	148	139	146	163	
1566	19	128	137	147	122	133	147	140	124	131	137	144
1571	16	121	138	157	135	144	156	145	138	145	153	
1584	27	136	158	165	129	139	161	147	132	138	146	159
1599	19	129	140	150	114	123	135	136	117	124	132	
1602	16	147	152	163	146	155	167	158	149	156	164	
1611	19	134	155	165	144	153	165	155	147	154	162	
1612	15	135	146	158	138	147	159	150	141	148	156	
1617	30	147	158	167	141	150	162	154	144	151	159	
1619	30	128	137	157	129	138	152	146	133	141	150	
1627	15	132	141	155	134	143	155	138	137	144	152	
1630	18	139	149	161	137	146	158	145	140	147	155	
1636	16	110	143	155	128	137	152	144	132	140	149	
1645	30	130	143	153	123	135	148	142	124	131	138	146
1650	15	135	136	150	128	137	149	141	131	138	146	
1653	12	132	142	148	140	149	161	152	143	150	158	
1656	9	122	141	152	140	149	161	149	143	150	158	
1658	17	128	135	142	125	135	147	142	128	135	143	
1661	20	121	137	146	137	146	159	147	140	147	155	
1664	18	132	141	148	128	137	149	145	131	138	146	
1676	7	112	122	126	110	119	137	121	113	119	126	135
1689	16	101	110	121	112	121	134	127	115	122	130	
1725	27	103	132	152	109	118	138	115	112	119	135	
1755	19	98	110	122	111	120	135	128	114	120	127	133
1784	15	110	119	138	114	123	143	134	117	124	139	
1825	30	130	141	160	127	136	148	144	130	137	145	
1835	24	130	141	161	129	138	150	145	132	139	147	
1842	15	121	123	134	113	124	145	134	116	124	141	
1909	17	127	140	156	137	146	158	148	140	147	155	
1917	16	133	138	141	123	132	144	136	126	133	141	
1920	15	128	134	140	123	132	144	136	126	133	141	
1924	17	135	140	156	133	142	157	144	135	141	146	154
1948	13	134	144	150	125	134	146	123	128	135	143	
1960	30	117	132	141	121	130	143	140	124	131	139	
1974	26	135	145	158	130	140	152	145	133	140	148	
1987	30	128	133	152	127	136	153	145	131	140	150	

TABLE 5.- RMSE FOR SPRING GRAINS PLANTING DISTRIBUTION MODEL AND FEYERHERM STARTER MODEL VERSUS 1979 GROUND TRUTH

	First Date	Median Date	Last Date
Spring small grains RMSE	7.91	6.61	7.09
Spring Bias	-0.3	+1.6	-0.1
Feyerherm RMSE	--	8.49	--
Feyerherm Bias	--	-2.9	--

In the northern Great Plains, there is a considerable, although limited, period when spring small grains may be planted with a reasonable probability of a high yield. If planted too early, the seeds may rot in the ground or the young plants may be damaged by a late frost. If planted too late, the crop may be heat or water stressed during flowering or it may be killed by a fall frost before grain-filling is complete.

In areas with a mild climate such as the Pacific Northwest or southern England, spring grains may be planted over a very long period. For example, in southeastern Washington in 1976, spring wheat planting continued for over 60 days (unpublished ESCS data). Increasing the length of the planting period to 40 or 50 days may make the model applicable in these regions.

When the model is used to start weather-based phenology models such as the Robertson spring wheat model (ref. 10), each of the representative dates should be used as a planting date. If weather-based models are developed to estimate spectral appearance in Landat imagery, such models could be run from our representative dates to generate the range of expected spectral appearance or signature at acquisition dates.

4. CONCLUSIONS

The GDDR variable indicates when planting may begin in the spring. The SPVAR function indicates when the soil is dry enough for field operations. The limit of 22 planting days is the result of fitting data to the 1979 planting dates for the U.S. Great Plains, and this limit will not hold in areas with a much longer or shorter planting period.

Compared to the Feyerherm starter model, this model provides additional information about the duration of the planting period. Although the new model more accurately estimates the 1979 median planting dates than the Feyerherm model does, it should be tested on independent data before it can be accepted as really being more accurate.

Overall, this model should work best in regions where spring small grains must be planted shortly after the beginning of the spring warm-up. These regions include the U.S. Great Plains, central Canada, and the northern and central spring grains regions of the U.S.S.R. In areas with a relatively long mild summer, such as the U.S. Pacific Northwest and Great Britain, the model will predict the beginning of the planting period, but will not predict the end without some adjustment. In areas where conditions are totally different, such as India and Australia, the model is not applicable.

The model provides a range of planting dates which may be used to start weather-based phenology models, yield models, and possibly spectral appearance models.

5. REFERENCES

1. Hodges, T.; and Doraiswamy, P. C.: Crop Phenology Literature Review for Corn, Soybean, Wheat, Barley, Sorghum, Rice, Cotton, and Sunflower. JSC-16088, LEC-13722, NASA/JSC (Houston), November 1979.

2. Feyerherm, A. M.: Planting Date and Wheat Yield Models. Prepared for NASA/JSC (Houston), under Contract NAS 9-14533.

3. Hodges, T.: Analysis of 1979 U.S. Spring Wheat and Spring Barley Periodic Ground Truth. JSC-16837, LEMSCO-15698, NASA/JSC (Houston), January 1981.

4. Trenchard, M. H.; Sestak, M. L.; Kinsler, M. C.; and Phinney, D. E.: Composition and Assembly of a Spectral-Met Data Base for Spring and Winter Wheat, vol. I and II. JSC-14901, LEC-13393, NASA/JSC (Houston), May 1979.

5. United States Environmental Data Service, 1979a: Climatological Data, Minnesota. National Oceanic and Atmospheric Administration, Environmental Data Service, vol. 85.

6. United States Environmental Data Service, 1979b: Climatological Data, Montana. National Oceanic and Atmospheric Administration, Environmental Data Service, vol. 82.

7. United States Environmental Data Service, 1979c: Climatological Data, North Dakota. National Oceanic and Atmospheric Administration, Environmental Data Service, vol. 88.

8. United States Environmental Data Service, 1979d: Climatological Data, South Dakota. National Oceanic and Atmospheric Administration, Environmental Data Service, vol. 84.

9. Trenchard, M. H.; and Artley, J. A.: SPONGE: A Pan Evaporation-Precipitation Balance Estimated from Daily Temperatures and Rainfall. (To be published.)

10. Cross, H. Z.; and Zuber, M. S.: Prediction of Flowering Dates in Maize Based on Different Methods of Estimating Thermal Units. Agronomy J., vol. 64, pp. 351-355, 1972.

11. Robertson, G. W.: A Biometerological Timescale for a Cereal Crop Involving Day and Night Temperatures and Photoperiod. Int. J. Biometeorol., vol. 12, pp. 191-223, 1968.